THE USE OF BONE-CONDUCTED MASKING NOISE WITH THE AUDITORY STEADY-STATE RESPONSE

CAPSTONE

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Audiology

in the Graduate School of The Ohio State University

By

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ABSTRACT

The present study investigated the feasibility of using a bone conducted masking noise to effectively mask an air conducted auditory steady-state response (ASSR) stimulus in normal hearing subjects. Ten normal hearing adults, ages 21 to 31, participated in this study. Behavioral and ASSR thresholds were measured for an air conducted (AC) 1 kHz mixed modulation tone in the presence of varying levels of bone conducted (BC) white noise in order to generate behavioral and electrophysiological masking level functions. Linear regression lines were fit to these data. Results of this investigation showed that BC white noise shifted both ASSR and behavioral thresholds in a linear fashion and that the behavioral and ASSR masking functions were strongly correlated with each other ($r = 0.761$, $p < 0.001$). Also, individual listener masking function slopes for ASSR and behavioral masked thresholds were significantly correlated ($r = 0.660$, $p < 0.05$). These results suggest that BC white noise can mask an AC 1 kHz mixed modulation tone during both behavioral and ASSR measures. The results also indicate that behavioral masking functions reasonably predict the occurrence and manner of threshold shift to BC masking noise in ASSR recordings.

Dedicated to my parents, Butch and Fran Keifer, and my wife, Laura

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

The air-bone gap (ABG) is one of the most important pieces of audiologic information used today. The ABG is the difference between an individual's air-conducted threshold (AC) and their bone-conducted (BC) threshold to a particular stimulus. For AC stimuli, sound is transmitted through the outer, middle and inner ears before detection can occur. With BC stimulation, a sound vibration is passed predominantly to the inner ear, bypassing (in most part) the outer and middle ear (although Tonndorf, 1968, described additional cochlear stimulation related to ossicular and outer ear vibration). A comparison of these threshold measures allows the audiologist to differentiate between sensorineural, conductive, or mixed type hearing losses. This differentiation is necessary for appropriate management, which can include medical intervention, aural (re)habilitation, and counseling. The ABG is commonly measured by behavioral methods in populations able to follow instructions and respond (i.e., button push, raise hand) when a signal is detected. Accurate measurements or estimates of the ABG are more difficult with individuals who are unable to perform behavioral tasks, such as infants, young children, multiply handicapped individuals, and malingerers.

1.1 Clinical Assessment of Infants

The advent of universal newborn hearing screenings (UNHS) and the emphasis on early detection and intervention has been a major step in ensuring that hearing impaired children are identified at an early age. This is necessary so that the appropriate auditory management can take place before the end of their critical period for acquiring language. Air conducted auditory brainstem response (AC-ABR) and otoacoustic emissions are the current techniques used in infant screening protocols. While these tools may indicate the presence of a hearing loss, there is no accurate differentiation between conductive and sensorineural hearing loss (Johnson, 2002).

1.1.1 Otoacoustic Emissions

Otoacoustic emissions (OAEs) are low-level sounds believed to be produced as a result of outer hair cell motility in the cochlea (Kemp, 2002). OAEs rely on normal or near-normal function of middle ear in order for the extremely low-level emissions generated by the inner ear to be conducted to the outer ear where they can be detected by a sensitive microphone (Johnson, 2002). An individual could very well present with absent OAEs, yet have normal cochlear function in the presence of a slight, mild, or maximum conductive hearing loss. On the other hand, given normal middle ear function, traditional clinical applications of OAEs have a low probability of being detected in frequency regions where hearing loss is greater than 30 dB HL (Harris & Probst, 2002). To summarize, OAEs are an efficient means to screen hearing in infants, but rely on normal or near normal outer, middle, and inner ear function. The absence of OAEs does not differentiate between types or degrees of loss.

1.1.2 Auditory Brainstem Response

The auditory brainstem response (ABR) is the most commonly used auditory evoked potential (AEP) for estimating hearing loss in individuals who cannot be tested with conventional behavioral measures. The ABR is a series of electrical potentials recorded from the scalp during the first 10-20 ms after the onset of a transient stimulus. ABR thresholds are determined by observing deflections in the time domain recording that represent synchronous activity produced by the neuronal response of the eighth nerve and auditory brainstem pathway (Stegeman et al., 1987). The most commonly used measures of this recorded waveform are the amplitudes and latencies of the peaks (waves). In the absence of any neurological pathology, ABR thresholds have been found to be closely associated with behavioral thresholds in both adult and infant populations (Sininger, 1993)

Using a bone oscillator to present a stimulus for ABR in order to help in differentiation of hearing loss type has been recommended for clinical use since the late 1970s, but currently remains under-utilized (Campbell et al., 2004). The reluctance by clinicians to use bone-conducted ABR (BC-ABR) may be due to several technical difficulties outlined by Campbell and colleagues (2004) including a narrow dynamic range for testing, masking difficulties, stimulus artifact, and an underestimation of low frequency hearing loss. The maximum output for a bone conduction transducer is about 55 dB nHL (referenced to normal hearing level for a specific signal) for a click stimulus. The generation of an air-conducted ABR wave V typically requires a level of 15-20 dB greater than the hearing threshold level. The combination of these two factors results in a narrow dynamic range to search within for an air-bone gap (Campbell et al., 2004). Masking difficulties in separating the response of the test ear from the response of the non-test ear has often been cited as a major problem. Cases with moderate bilateral conductive components can result in the cross-over of the signal and the masker, resulting in a masking dilemma (Campbell et al., 2004). Electrical and magnetic energy from a bone oscillator can produce a substantial amount of artifact. When this artifact is great, it can be mistaken for a physiological response or obscure the response (Campbell et al., 2004). An underestimation of low frequency hearing loss can occur due to the fact that conductive hearing loss is usually the greatest below a frequency of 1000 Hz and the click stimulus commonly used in ABR (click-ABR or c-ABR) testing has the majority of its energy between 1000 and 4000 Hz. The use of tone burst ABR (tb-ABR), however, has been used to give a fuller picture of hearing loss estimation (Campbell et al., 2004).

1.1.3 Auditory Steady-State Response

Another type of AEP is the auditory steady-state response (ASSR). This type of electrophysiologic measure uses a modulated tone as a stimulus. The modulation can be either in frequency (FM), amplitude (AM), or a combination of the two (mixed modulation). The continuous modulation elicits periodic "steady-state" waves that are phase-locked to the modulation envelope (Stueve & O'Rourke, 2003). The recorded response is spectrally analyzed for magnitude and phase characteristics at the particular modulation rate for the stimulus. By comparing the energy and/or phase characteristics at the modulation rate to the adjacent noise in the side bands, the ASSR software uses statistical analyses to determine if a response is "present" in the ongoing electroencephalogram (EEG) recording. This response detection software does not rely on the experience and subjective judgment of the clinician to interpret a time domain waveform, as seen with some common applications of the ABR. This allows for an increased level of objectivity with ASSR over ABR. Another advantage is that, since each carrier tone can have its own modulation rate, multiple auditory stimuli can be presented simultaneously. This allows for a great deal of frequency specific information to be acquired, without significantly increasing the total testing time in comparison to the ABR (Small & Stapells, 2004). The most glaring disadvantages with ASSR are that the body of literature examining the usefulness and application of the ASSR is, while growing, still relatively small and that "standard protocols for measuring ASSR have yet to be established and continue to be refined" (Stueve & O'Rourke, 2003, p. 126). As a likely result, ASSR has not been widely accepted as a more effective and efficient tool compared to ABR.

1.2 Background and Rationale

A reliable protocol for using non-behavioral measures in making accurate estimates of the ABG in difficult-to-test populations is needed. From the aforementioned measures, it seems reasonable that potential may lie in the use of the ASSR for just such a protocol. In a recent study by Small and Stapells (2004), the authors cited numerous studies that demonstrated ASSR recordings to AC stimuli "have been found to provide an accurate prediction of hearing sensitivity at the audiometric frequencies" (p. 612). Clinically, this fits well with the way other audiometric information is represented (i.e, the audiogram, AR thresholds). To date, however, very few studies using ASSR to estimate BC thresholds have been published. Most studies have made use of a bone conducted stimulus to directly elicit a response from the auditory system (Lins et al., 1996; Dimitrijevic et al., 2002; Campbell et al., 2004; Jeng et al., 2004; Small & Stapells, 2004; Small & Stapells, 2005; Small & Stapells, 2006; Small et. al, 2007). A consistent report from these studies was that of significant problems with stimulus artifact.

1.2.1 Artifact Associated with BC-ASSR Recordings

In an ASSR recording, the stimulus and response overlap in time. The relatively low analog-to-digital (A/D) conversion rates (500 or 1000 samples/sec) typical of ASSR software can allow for electromagnetic (EM) energy from the bone oscillator transducer that is present in the EEG to be aliased to the same frequency as the ASSR modulation rate (Small & Stapells, 2004). This is typically not an issue with AC due to very low EM artifact amplitude. Aliasing can occur for any frequency higher than half of the sampling rate (Nyquist), resulting in energy components that were not in the original signal. This aliased energy can be interpreted as a response. Small and Stapells (2004) explained how this could occur for a 500 Hz sampling rate:

> For example, a 500 Hz tone that is amplitude-modulated at 77 Hz would have energy at 423, 500, and 577 Hz. If this energy is present in the EEG being digitized at 500 Hz, an alias frequency would be 500 Hz - 423 Hz = 77 Hz, which is exactly the same as the modulation rate for this 500 Hz carrier frequency. When standard audiometric frequencies (500, 1000, 2000, and 4000 Hz) are used as carrier frequencies to elicit ASSRs, this calculation predicts that aliasing will be a

potential problem for all of the carrier frequencies when using a 500 Hz A/D rate. Similarly, using a 1000 Hz A/D rate, aliasing will be a potential problem for 1000, 2000, and 4000 Hz carrier frequencies but not for a 500 Hz carrier frequency. (p. 613)

The research by Small and Stapells (2004) investigated direct BC-ASSR under different conditions including single vs. multiple stimuli, carrier frequency selection, and A/D conversion rates (500, 1000, 1250 Hz) with subjects who had severe to profound sensorineural hearing loss. The ASSR stimuli were verified as inaudible with subjects prior to recording so that any response elicited was considered spurious. The bone conduction results for the 500 and 1000 Hz sampling rates revealed artifactual responses as low as 20 dB HL for the 500 Hz carrier frequency and at 40 dB HL and 50 dB HL for 1000 and 2000 Hz carrier frequencies. Alternating stimulus polarity and using a 1250 Hz A/D rate with the addition of an anti-aliasing filter (115dB/oct slope) increased the levels at which artifactual responses were recorded for the 500 and 1000 Hz carrier frequencies to 50 dB HL and 60 dB HL, respectively. There were no responses recorded for 2000 and 4000 Hz.

The authors concluded that aliasing of EM energy can be managed to some extent by using higher sampling rates (A/D rates), using a rate which is not an integer multiple of the carrier frequency, careful adjustment of filter parameters with steep attenuation rates, and/or alternating the stimulus polarity and averaging inverted and non-inverted responses (Small & Stapells, 2004). They postulated that the artifact still present may be due to non-auditory physiologic responses and that while the careful selection of recording parameters will help to avoid aliasing artifact, spurious responses can still occur for any patient when BC stimuli are at levels greater than 40 dB HL. In addition, many of the clinical ASSR systems available do not allow for the A/D rate to be manipulated, built-in alternation of stimulus polarity is not common, and the attenuation rates for the filters are relatively low (6 or 12 dB/octave). They also noted a drawback to using higher A/D rates may increase the overall noise estimate and make a true response fail to reach significance.

In a separate study by Jeng and colleagues (2004), the authors compared ABG estimation using ASSR with traditional behavioral measures in 10 normal hearing adult subjects with varying degrees of simulated conductive losses. Also, 5 profoundly hearing impaired cochlear implant wearers were used to determine levels at which stimulus artifact became problematic. Two materials, epoxy and lamb's wool, were used to block the tip of the insert earphone to create artificial ABGs to levels of 30-60 and 15-30 dB, respectively. Behavioral and electrophysiological AC and BC measures for each type of material were recorded and used to estimate ABGs. The results indicated that ASSR-estimated ABGs and audiometric ABGs were strongly correlated with each other. The authors admit that the major limitation is that the results reflect artificially created conductive hearing losses. For the 5 cochlear implant wearers, results indicated that the levels where BC stimulus artifact can cause a spurious response were 53, 36, 54, and 53 dB HL at 500, 1000, 2000, and 4000 Hz, respectively. These levels correspond well to the results found by Small and Stapells (2004) and represent a major limitation to direct BC threshold measures. Jeng and colleagues suggest that an alternative approach which does not require the ASSR stimulus to be presented by bone conduction should be investigated.

1.2.2 The Sensorineural Acuity Level (SAL) Test

In 2002, Cone-Wesson and colleagues had already used that alternative approach to estimate the ABG with ASSR in infants by using the Sensorineural Acuity Level (SAL) test (Jerger & Tillman, 1960; Jerger & Jerger, 1965). The SAL test employs the use of a BC noise to mask an AC stimulus presented just above an individual's unmasked threshold. The amount of effective masking (EM) through BC is used to estimate BC thresholds. For example, the amount of BC masking noise necessary to mask AC thresholds is determined for a group of normal hearing listeners. For individuals with a conductive hearing loss (CHL), AC thresholds will be elevated while the level of BC masking will be the same as for normal listeners. Listeners with a sensorineural hearing loss (SNHL) will have BC masking levels that will be elevated along *with* AC thresholds. And finally, for a mixed hearing loss (MHL) the level of BC masking would be used to estimate the sensorineural loss and the difference between BC and AC estimates the air-bone gap.

1.2.3 Application of the SAL Test to Auditory Evoked Potentials

The SAL test was first adapted to BC-ABR by Hicks in 1980. Her study measured ABR thresholds for AC clicks in quiet and in the presence of BC masking (high pass-filtered noise delivered through forehead placement of a bone oscillator). This was conducted on 15 normal hearing listeners and for 4 individual cases with sensorineural, conductive, or mixed hearing losses. The measures were repeated for 5 of the normal hearing listeners after an earplug was used to create an artificial conductive hearing loss. Responses were recorded at 5 dB above threshold level (ABR + 5) and found that the level of high-pass noise minus 15 dB approximated the sensorineural pure-tone thresholds. Hicks also found that one of the primary advantages of using the SAL technique over more direct BC measures was the "ease of calibration and minimal or no nontest ear contribution" (p. 395).

Webb and Greenberg (1983) followed up with a study aimed at providing more extensive verification of the SAL approach with the addition of tone-pip stimuli for more frequency-specific information. Four groups of subjects were used in this study. Group 1 consisted of 10 normal listeners. Group 2 used the 10 normal listeners from group 1 but with monaural artificially occluded ears (E. A. R. plug). Group 3 included 10 listeners with mild or moderate sensorineural hearing loss. Group 4 subjects were the same listeners from group 3, but with binaural artificially occluded ears (E. A. R. plug) to simulate mixed losses. Behavioral measures of the ABG were compared to ABR estimates using a similar method to what Hicks (1980) had used with ABR thresholds plus 5 dB (ABR + 5) as the AC stimulus levels to be masked. The BC masking noise was 10 kHz broadband noise delivered through forehead placement of a RadioEar B-71 bone oscillator. Derived bone-conduction thresholds were obtained by subtracting the mean level of noise used to mask ABR + 5 in the group of normal listeners from the noise level found for each listener. The results of this study showed close agreement between derived BC thresholds and behavioral BC thresholds for all subject groups except the mixed loss group. The authors only gave a possible explanation that these subjects had the most difficult potentials to interpret and replicate and that they often had difficulty discerning when ABR + 5 had been masked. In addition to the lack of agreement for mixed losses, other limitations were noted as the great deal of time required to derive frequency specific BC thresholds for each ear using tone-pips. Webb and Greenberg found that the worst sensorineural deficit that could be assessed was approximately 40-50 dB HL, similar to Hicks' findings from 1980 of up to 50 dB HL. Finally, the authors noted some contamination of myogenic artifact that may have been controlled by selecting different filter settings.

Ysunza and Cone-Wesson (1987) investigated the SAL ABR approach with a population of 23 subjects with unilateral or bilateral microtia/atresia (30 ears). These children were older than 3 years and cooperative enough for conventional behavioral AC and BC measures. A control group of an equal number of ears (30) with sensorineural hearing loss was also assembled. Standard ABR recording procedures were used to find thresholds to a click stimulus. An Oticon 55786 bone oscillator in a forehead placement was used to deliver a wide-band masking noise in increasing levels until the ABR threshold plus 5-10 dB HL was masked. They found a high specificity (100%) and sensitivity (96%) for the differentiation between conductive and sensorineural hearing loss. The authors noted the main limitation of this procedure was its inability to estimate the cochlear reserve in mixed impairments where the amount of loss was greater than 60 dB HL. This was due to the maximum output of the bone oscillator being 50 dB HL.

Janssen and colleagues (1993) developed correction factors necessary for accurate estimation of the ABG. They called these the *masked threshold to noise ratios* or *MTNRs*. This study used 21 normal-hearing adults (one ear was randomly picked) and repeat measures for 10 of these subjects after the induction of an artificial conductive loss using an earplug. Standard c-ABR recording procedures were applied. White noise was presented via forehead placement of a B70A bone oscillator. C-ABR levels were fixed at 5-15 dB above the AC threshold. BC masking noise was increased until wave V disappeared. The MTNR was defined as "the difference of the (fixed) click stimulus level and the highest masking noise level that still yields a response with a replicable peak V" (p. 156). The results of this study indicated a MTNR of -13 dB +/- 5 for normal hearing subjects. The authors concluded that the conductive loss component, or ABG, could be calculated by adding 13 dB to the measured MTNR, but that this procedure was limited to detection of ABGs in subjects with sensorineural hearing losses of up to 50-55 dB.

In 2002, Cone-Wesson and colleagues published work extending the use of the SAL technique to ASSR. This study included 39 infants ages 3-13 weeks with risk factors for hearing loss and 2 children with sensorineural hearing loss documented by Pure-tone Audiometry. The infants had a c-ABR, DPOAEs, and Tympanograms prior to ASSR measures. The ASSR protocol used 100%AM + 15%FM (mixed modulation) 1000Hz tone at mod-rate of 81Hz to obtain AC thresholds. A RadioEar B70 bone oscillator coupled to an audiometer was used to present narrow band noise (NBN) centered on the carrier frequency of the stimulus. Infants were grouped into 4 categories based on c-ABR, DPOAEs, and Tympanometric results. The groups were: (1) Control (normal ABR, DPOAEs, and Tympanograms), (2) Indeterminate (normal ABR, abnormal Tympanograms, and absent DPOAEs), (3) Presumed Conductive (absent DPOAEs, abnormal Tympanograms, elevated ABR), and (4) Presumed Sensorineural (absent

DPOAEs, elevated ABR, normal tympanograms). ASSR results were analyzed for their ability to estimate AC thresholds and ABGs. The authors concluded that the study "demonstrated that it was possible to estimate AC and BC masking thresholds in infants at risk for hearing loss" (Cone-Wesson et al., p. 274). The main limitation of this study was the lack of behavioral confirmation of threshold estimates obtained by ASSR.

1.3 Research Objectives

The current study was designed to investigate the validity of the most basic underlying assumption necessary when using a BC masker to mask AC ASSRs—that masking occurs in a predictable and effective manner under the conditions used with application of the SAL test to ASSR. This serves as the preliminary work to long-term research goals of applying the SAL technique to ASSR as a method to estimate the ABG of adult and, ultimately, infant/child populations with CHL.

The specific goal of this study was to determine whether a BC white noise can effectively and predictably mask ASSR thresholds to a 1 kHz MM stimulus in normal hearing adults. Behavioral and ASSR data were used to determine: (1) if AC ASSR thresholds could be masked by BC noise, (2) whether increases in BC noise level result in increases of ASSR threshold levels, and (3) whether behavioral masking functions predict the occurrence and manner of threshold shift to BC masking noise in ASSR recordings.

CHAPTER 2

MATERIALS AND METHODS

2.1 Listeners

Ten normal hearing young adults (5 male, 5 female), 21 to 31 years of age, were recruited for this project. Participants came entirely from the student population of the university and were given a preliminary audiological examination to ensure that they had normal hearing. This examination included otoscopy and a pure-tone screening at 250, 500, 1000, 2000, and 4000 Hz. Thresholds equal to or better than 20 dB HL were required at all frequencies for participation in this study. The individual listener audiometric data are given in Appendix A. The left ear was the test ear for all subjects. This ear was chosen for ease of access and visual placement of the bone oscillator (left ear faced booth entrance when listener was reclined for ASSR measures).

2.2 Stimulus and Instrumentation

The tones used to elicit the ASSR are described as having a carrier frequency, with amplitude (AM) and frequency (FM) modulation. The combination of AM and FM constitutes what was referred to as mixed modulation (MM). The modulation rate is followed by the auditory system and allows for a response in the ongoing EEG to be extracted. The stimulus used for this study had a carrier frequency of 1000 Hz with

100% AM and 15% FM mixed modulation at 81 Hz. The relative phase between AM and FM was 90° [0° defined as the phase relationship where the maximum frequency occurs at the same time in the waveform as the maximum amplitude (John et al., 2001)]. The relative phase of 90° between AM and FM allows for the maximum amplitude to correspond to the carrier frequency (1000 Hz). The waveform and spectral estimate of this signal are shown in Figure 2.1. The first spectral sidebands and located at the frequencies given by the carrier frequency plus and minus the modulation rate (919 Hz 1081 Hz) are 9 dB down from the peak (referenced to 0 dB). The secondary sidebands (carrier +/- 2 times the modulation rate) are 32 dB down, and the third sidebands are 62 dB down.

For behavioral data collection, the 1000 Hz MM (81Hz) stimulus was created using the parameters defined above with MATLAB software as a .wav file (sampled at 20 kHz). The MM stimulus was recorded onto an audio CD and played through an external channel on the GSI-61 audiometer. A 1000 Hz pure tone equal in peak-to-peak amplitude to the MM stimulus was also recorded on the CD and used as a calibration tone.

During ASSR recording, the MM stimulus with aforementioned parameters was created using the IHS SmartEP system stimulus generation utility (sampled at 20 kHz). Assuming that all stimulus parameters were equivalent (i.e., modulation rate, carrier frequency, AM depth, FM %, phase relationship, and sampling rate), the waveform and spectral content were assumed equal to the stimulus created in MATLAB. The ASSR stimulus output level was calibrated by using the IHS SmartEP system calibration utility. Once inside the utility, the stimulus file was selected along with a nominal output level

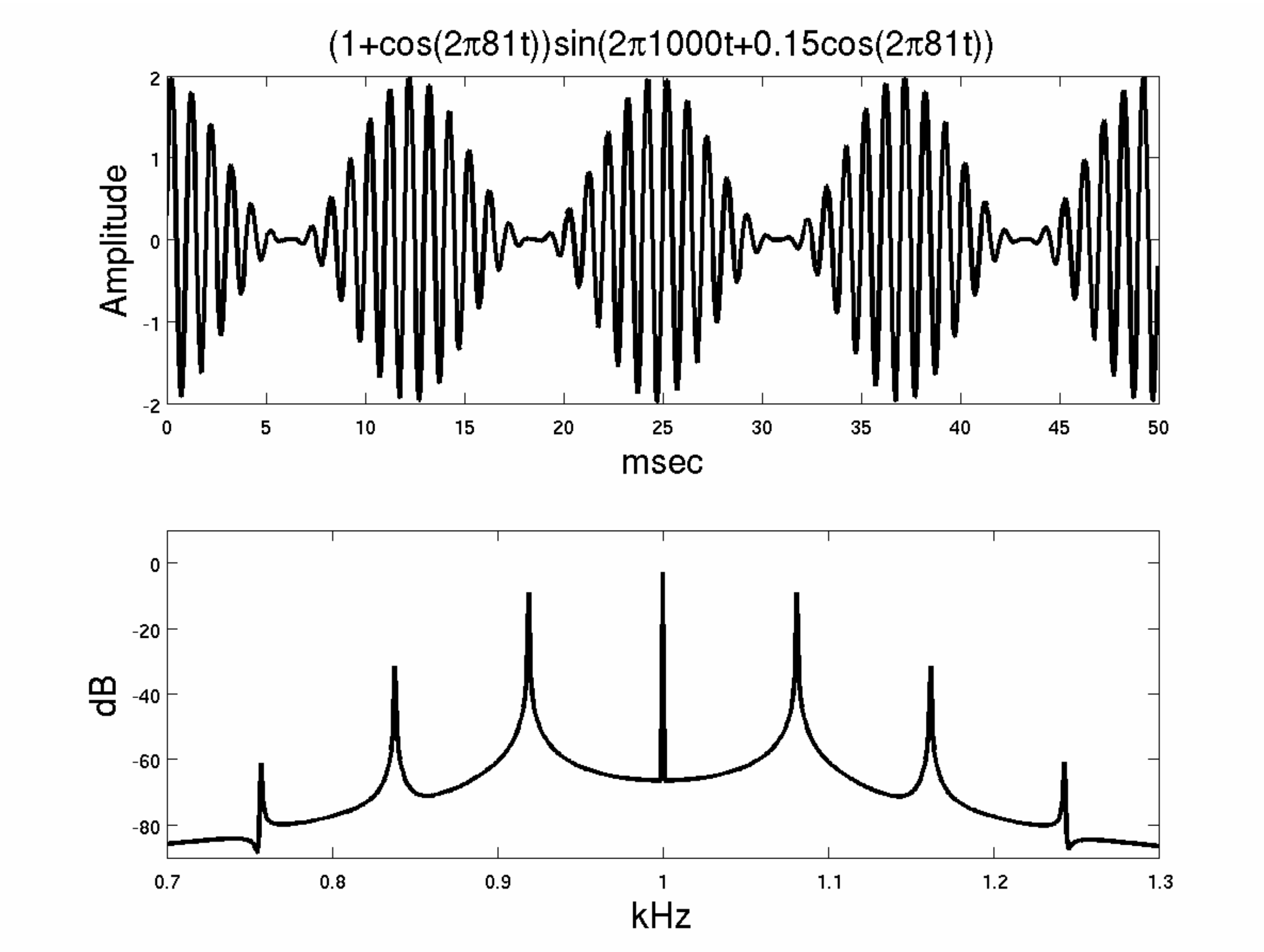

Figure 2.1: Waveform and spectral estimate of the 1000 Hz MM (81Hz) stimulus. This signal has 100% amplitude modulation and 15% frequency modulation. First sidebands are approximately 9 dB down, second sidebands 32 dB down, and third sidebands 62 dB down from referenced peak (1000 Hz).

(i.e., 60 dB SPL). A Larson & Davis system 824 model sound level meter with ½" microphone connected to a Zwislocki coupler was set to measure dB SPL within a 1-octave filer centered on 1000 Hz. After the earphone was inserted into the coupler, the MM stimulus was presented. Correction factors were applied as necessary from within the IHS calibration utility to meet the specified nominal level. The output was also checked in the IHS SmartEP ASSR module recording mode to ensure calibration corrections had been applied.

2.2.1 Behavioral measures

Behavioral measures were obtained using a GSI-61 audiometer to present the pre-recorded 1000 Hz MM stimulus (described in section 2.2) through E-A-RTONE 3A insert earphones. The BC masking noise was presented through a RadioEar B-71 bone oscillator coupled to a calibrated GSI-16 clinical audiometer, which was located outside of the test booth. This audiometer and bone oscillator was used to generate white noise (WTN) as the masker. This type of noise was selected following pilot data that indicated white noise masked behavioral thresholds more predictably than a narrow-band noise centered on 1000 Hz (Appendix B). The WTN generated by the GSI-16 had equal energy per 1 Hz bands from 250 to 6000 Hz. The bone oscillator was worn in a high mastoid position to coincide with the set-up for the electrophysiological portion of this study. The listener used a response button to indicate when the stimulus was detected.

2.2.2 ASSR Measures

The acquisition of ASSR measures required listeners to wear E-A-RTONE 3A insert earphones, surface electrodes, and a RadioEar B-71 bone oscillator. The electrode leads were connected to an electrically isolated pre-amplifier located inside the test booth, which was connected directly to an IHS SmartEP system with ASSR module. The insert earphones connected directly to the IHS SmartEP system. Recordings were analyzed by the IHS SmartEP with ASSR module software and saved to the hard drive of the PC in which the IHS system communicates.

Electrodes were placed on the: (1) forehead near the hairline (Fz) which served as the positive recording or non-inverting electrode; (2) On the promontory of the mastoid behind the test ear (left) which served as the negative recording or inverting electrode; (3) On the promontory of the mastoid behind the non-test ear which served as a ground (common) electrode. For this study, absolute impedances for the electrodes were ≤ 3 kΩ and the between electrode impedances were ≤ 2 kΩ for testing to proceed. If these impedance standards were not met then the electrode(s) were removed, the skin re-cleansed and the electrode(s) reapplied. The impedance was rechecked and/or the procedure was repeated until values were within the established standards for the study before ASSR recording could begin.

The EEG was collected using the IHS system defaults. The responses were amplified by a gain of 100,000 and filtered using an analog band-pass filter of 30 to 300 Hz (6 dB/Octave) before being digitized. The A/D conversion was 1024 points at 1000 Hz for each recorded epoch 1.00 sec in length. Individual epochs were rejected if it contained voltages greater than +/- 31 μV. A selected total of 180 epochs were recorded for each masking/stimulus intensity level. The IHS SmartEP with ASSR uses an F-statistic to determine whether the spectral energy at the modulation frequency is significantly higher than the noise level in the adjacent side-bins (5 above and 5 below). Any response with an alpha level of 0.05 or less was considered to be a statistically significant response.

The RadioEar B-71 bone oscillator was coupled to a GSI-16 clinical audiometer, located outside of the test booth. This audiometer and bone oscillator was used to generate the WTN masker. Prolonged wear of the RadioEar B-71 and headband necessitated the use of a large (3" diameter) suction cup positioned on the end of the headband opposite to the bone oscillator. This allowed for increased comfort during extended use (approximately 2 hours during 2^{nd} session) by spreading the application force over a larger area, thus reducing pressure.

2.3 Procedures

Prior to testing and data collection, participants were given the Consent for Participation in Social and Behavioral Research to read and sign. Subjects were compensated for their time. Hearing screenings, behavioral measures, and ASSR unmasked thresholds were all obtained in one session while ASSR unmasked threshold re-checks and ASSR masked thresholds were obtained in a second session. Compensation consisted of a monetary payment given to the subject at the end of each session, which was based on the duration of the session. All subjects were required to sign a Payment Record Form to reflect these reimbursements and compensations.

2.3.1 Behavioral Measures

Stimulus thresholds in quiet and during masking were obtained by using routine clinical threshold estimates (i.e., modified Hughson-Westlake procedure (Carhart & Jerger, 1959)). Listeners were instructed to respond only when they heard the stimulus and to ignore the masking noise when presented. Once an unmasked threshold was obtained, the masking noise was presented via bone conduction starting at the lowest audiometric level (-10 dB HL re: effective masking for a 1000 Hz pure tone) and increasing in 5 dB steps while masked AC thresholds were obtained. This procedure was repeated until the limits of the GSI-16 BC noise were met (60 dB HL for WTN).

2.3.2 ASSR Measures

Each listener's ASSR thresholds to the AC stimulus were recorded in quiet and masked conditions. Masked conditions represent the application of the WTN presented through bone conduction. Once electrodes and leads were attached, the listener was seated inside the booth in a reclining chair. Following confirmation of acceptable electrode impedances, insert earphones used to present the AC stimulus were placed into both the test ear (left ear for all subjects) and non-test ear. The RadioEar B-71 bone oscillator was coupled to the head behind the ear at a high-mastoid placement (superior and posterior) with an attached headband to avoid close contact with the inverting electrode.

Once seated and relaxed in the booth with insert phones, bone oscillator, and electrodes in place, ASSR recordings began. Unmasked thresholds for ASSR measures were considered to be the lowest level at which a response was recorded 2 of 3 trials.

This method was designed to reduce the chance that a spurious artifact is mistakenly labeled as a response. Unmasked ASSR thresholds are given in Appendix C.

Once the unmasked threshold was obtained, bone-conducted masking noise was presented at 10 dB HL (unless a shift in ASSR threshold occurred that was greater than 5 dB, in which the masking level was decreased to 0 dB). The stimulus levels were increased in 5 dB steps until a significant response is recorded. During ASSR masked recordings, the return of one significant response was accepted as masked threshold. When a response was recorded that did not result in a shift of stimulus level of greater than 5 dB, then the masking noise level was increased by 10 dB and the masked threshold was again obtained. Once the stimulus response shifted more than 5 dB, then masking level steps went to 5 dB. This process continued until the limits of the GSI-16 audiometer for the masking noise were reached (60 dB HL) or the AC ASSR stimulus reached 90 dB SPL. Using (1) the first response during masked thresholds and (2) 10 dB masking level steps until ASSR response shifts of greater than 5 dB occurred were deemed necessary procedures in order to reduce the total ASSR in-booth recording time for each listener to approximately 2 hours or less.

2.3.3 Data Analysis

The data obtained in this study was used to construct behavioral and electrophysiological (ASSR) masking level functions. These masking level functions were used to demonstrate the extent to which changes in BC masking level affect AC threshold. Linear regression and correlation analyses were applied to the data.

CHAPTER 3

RESULTS

SPSS 14.0, SigmaPlot 10.0, and Microsoft Excel software were used to analyze and generate graphs for all data. Prior to all analyses, data points collected at the beginning of BC masker presentation during behavioral measures that did not result in a shift of threshold were removed to ensure that results reflected the occurrence of masking. Data point exclusion for ASSR measures was not performed prior to all data analyses and occurred only where specifically noted in the following results. ASSR measures were handled more conservatively due to smaller number of data points and an increased difficulty in determining the point at which masking began.

3.1 Individual Listener Data

Figure 3.1 includes individual listener plots for both behavioral and ASSR masked threshold data (Appendix D). Note that stimulus and masker level data (ordinate) are unconverted so that each plot has a different dB reference (behavioral levels are dB HL and ASSR threshold levels are dB SPL). Open circles represent masked ASSR data and closed circles represent the behavioral data.

Figures 3.2 and 3.3 are combined scatter plots of individual listener masked thresholds for behavioral and ASSR measurements, respectively. The abscissa represents

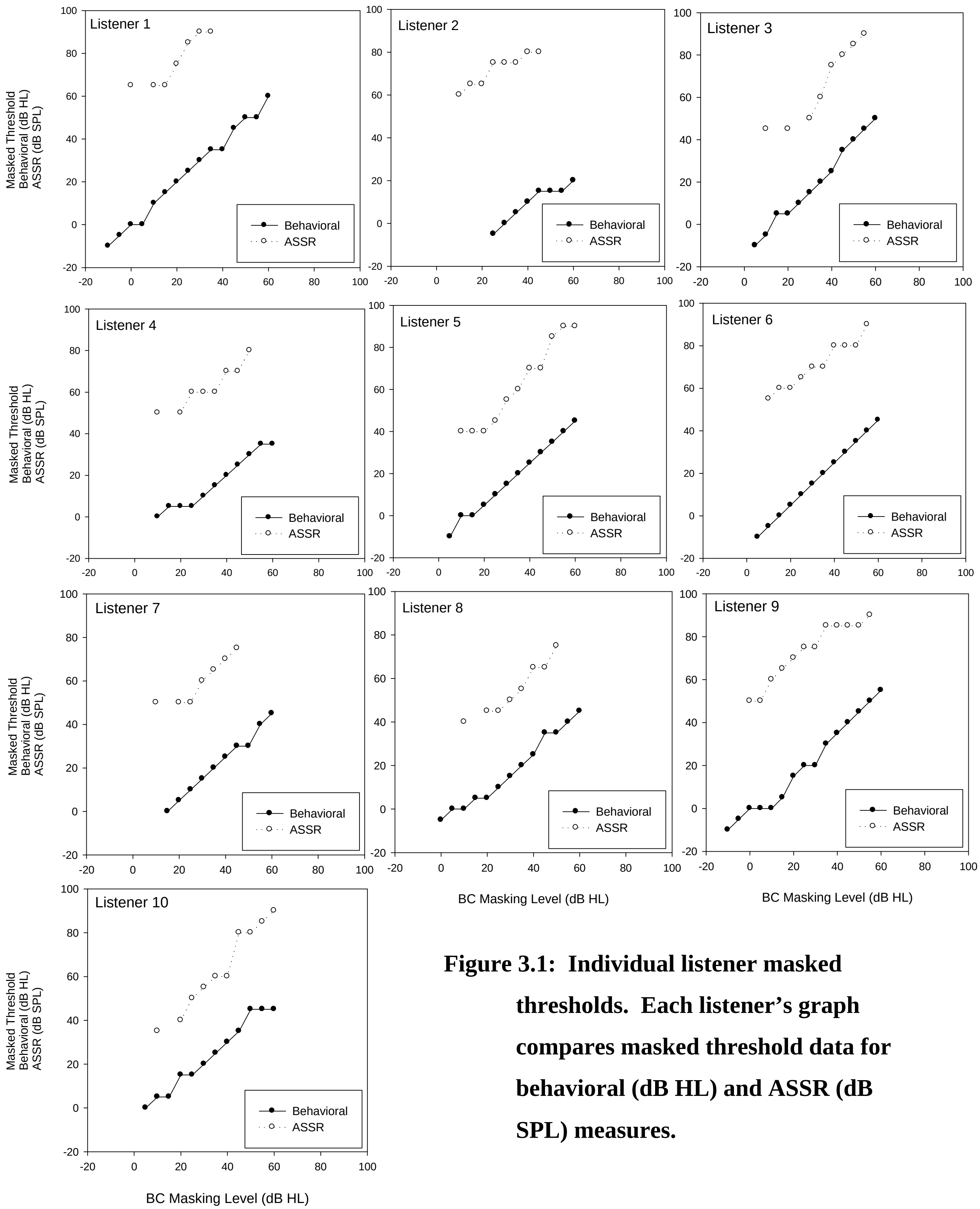

Figure 3.1: Individual listener masked thresholds. Each listener's graph compares masked threshold data for behavioral (dB HL) and ASSR (dB SPL) measures.

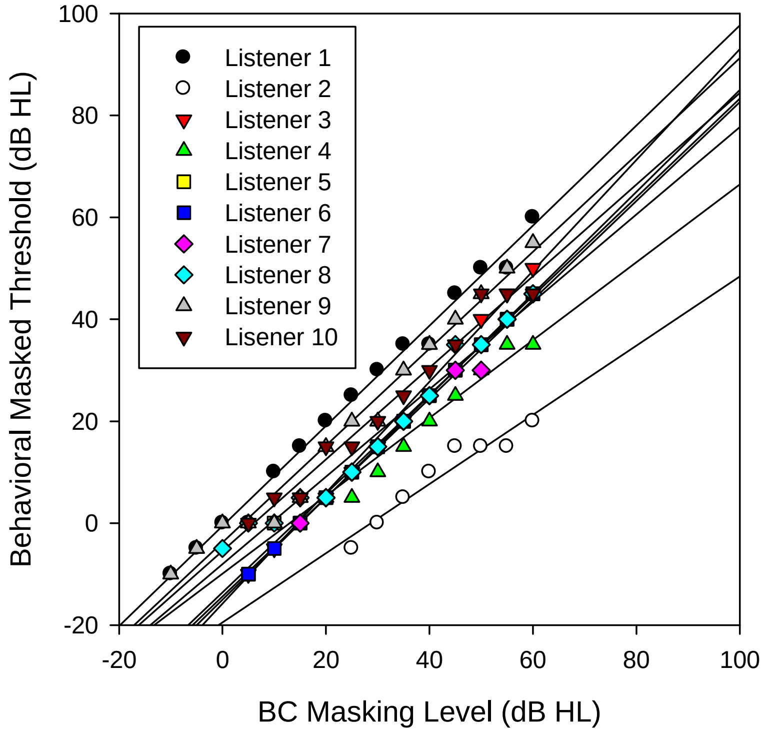

Figure 3.2: Individual listener behavioral masking functions.

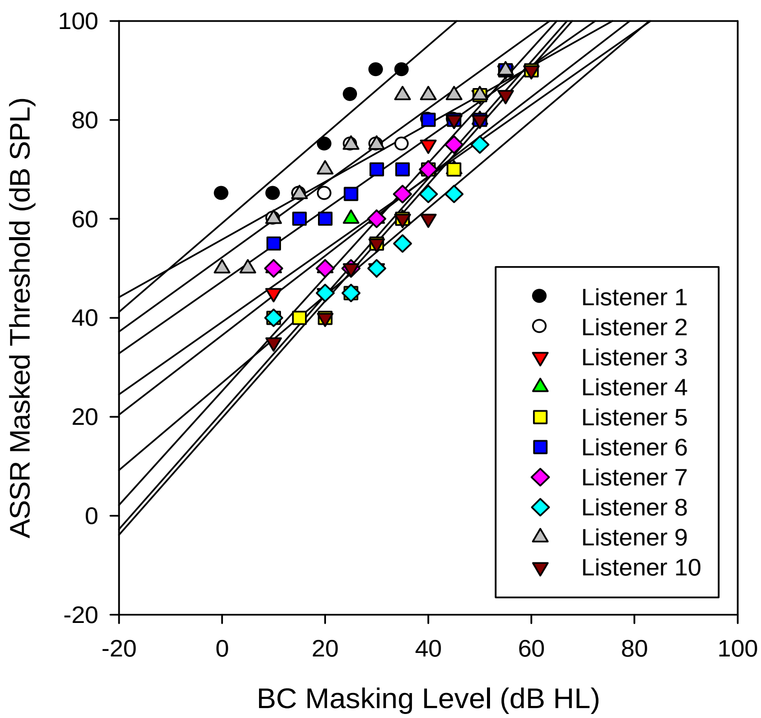

Figure 3.3: Individual listener ASSR masking functions.

the BC masking level, and the ordinate represents the behavioral thresholds and ASSR thresholds, respectively. In these figures, data from the ten different listeners are represented with different symbols and colors. The solid lines represent the results of linear regression analyses for each individual.

Table 3.1 summarizes the individual slopes obtained from linear regression for both behavioral and ASSR measures. The mean behavioral masked threshold slope was 0.915 with a standard deviation of 0.121. The mean ASSR masking function slope was 0.889 with a standard deviation of 0.213. Behavioral-to-ASSR slope ratios (BTASRs) are calculated in the right most column. BTASRs equal to 1 would represent an ideal relationship. The mean BTASR was 1.06 with a standard deviation of 0.196.

Listener	Behavioral Slope	ASSR Slope	Behavioral-to-ASSR Slope Ratio
1	0.982	0.898	1.09
2	0.679	0.583	1.16
3	1.09	1.15	0.948
4	0.764	0.732	1.04
5	0.969	1.18	0.821
6	1.00	0.727	1.38
7	0.97	0.803	1.21
8	0.857	0.882	0.972
9	0.95	0.752	1.26
10	0.89	1.18	0.754
Mean	**0.915**	**0.889**	**1.06**
Std Dev	**0.121**	**0.213**	**0.196**

Table 3.1: Summarized individual listener slope data from regression analyses.

It would be expected that if masking with behavioral and ASSR represent the effects of the same underlying mechanisms, then an individual's behavioral masking level slope may be a good predictor of their ASSR masking level slope. Individual listener ASSR masking function slopes are plotted against corresponding behavioral masking function slopes in Figure 3.4. The two were significantly correlated with a value of 0.550 ($r^2 = 0.303$, n = 10, $p = 0.05$, one-tailed). The solid line represents the result of linear regression, which has a slope of 0.968.

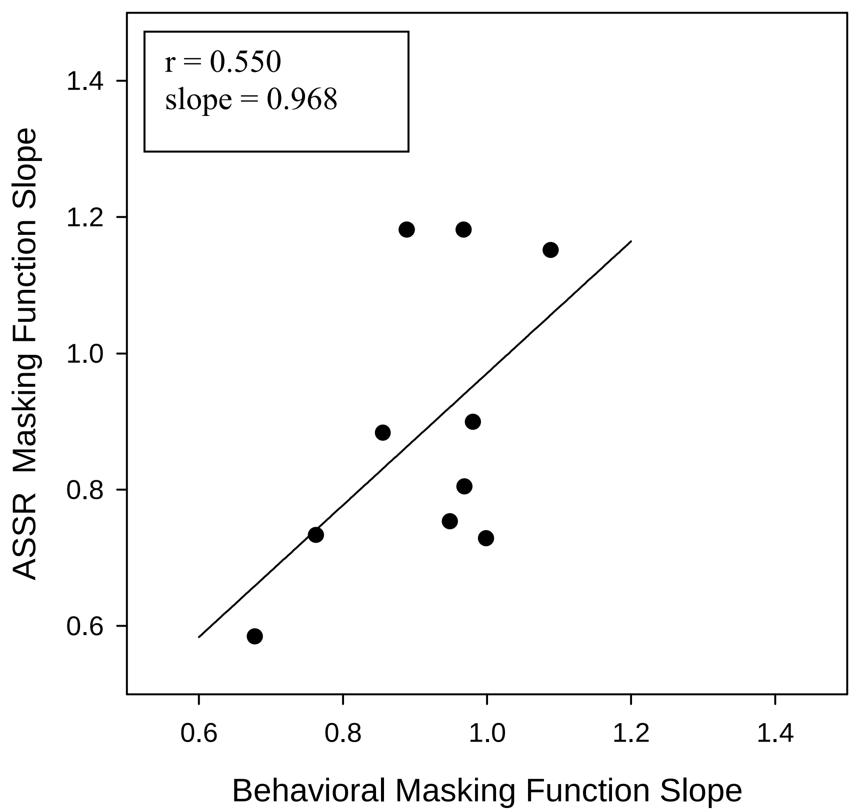

Figure 3.4: Comparison between individual listener behavioral masked threshold slope and ASSR masked threshold slope. The solid line represents the result of linear regression.

As mentioned previously, behavioral masked threshold data were edited prior to all data analyses in an attempt to obtain results which reflected thresholds that were truly masked. This was easily done by eliminating thresholds which did not shift by 5 dB or less from the listeners' unmasked thresholds. ASSR masked thresholds were much fewer in number (limited by dynamic range of response level to limits of the equipment) also proved to be less consistent. The determination of the precise level at which masking began was more difficult. In several cases, plateaus of three and four points were recorded in the middle of the masking level functions. Because of this variability, a more conservative approach was taken and all previous results to this point have represented unmodified ASSR masked threshold results.

In an attempt to determine what impact the deletion of ASSR masked threshold points at the beginning of masking level functions would have, the following individual results have been edited (Table 3.2 and Figure 3.5). Specifically, all ASSR data points at the beginning of masking that did not result in a change of threshold were removed, except the last point before a threshold change occurred. For example, referring back to Figure 3.1, listener 5 had masked ASSR threshold points at 40, 40, 40, 45, 55, 60, 70, 70, 85, 90, and 90 dB SPL. Data set modification resulted in the removal of the first two points. This process resulted in changes for listeners 1, 3, 4, 7, 8, and 9. The adjusted ASSR masked threshold slopes (italicized and bold) from linear regression are presented in Table 3.2. Note the change in mean ASSR slope from 0.889 to 1.01. The mean BTASR was minimally affected by adjusting the ASSR thresholds (0.961 +/- 0.237) and is still very close to a value of 1.

Listener	Behavioral Slope	ASSR Slope	Behavioral-to-ASSR Slope Ratio
1	0.982	***1.30***	0.755
2	0.679	0.583	1.16
3	1.09	***1.43***	0.762
4	0.764	***0.857***	0.891
5	0.969	1.18	0.821
6	1.00	0.727	1.38
7	0.97	***1.20***	0.808
8	0.857	***0.882***	0.972
9	0.95	***0.727***	1.31
10	0.89	1.18	0.754
Mean	**0.915**	**1.01**	**0.961**
Std Dev	**0.121**	**0.286**	**0.237**

Table 3.2 Summarized individual listener regression slope data (adjusted ASSR).

The individual listener behavioral and *adjusted* ASSR masked threshold slopes are plotted in Figure 3.5. The two were significantly correlated with a value of 0.660 ($r^2 = 0.435$, n = 10, $p < 0.05$, one-tailed). The solid line was the result of linear regression, which had a slope of 1.56. This indicated that the adjusted ASSR slopes were slightly better predicted by behavioral slopes when compared to the un-edited ASSR slope values.

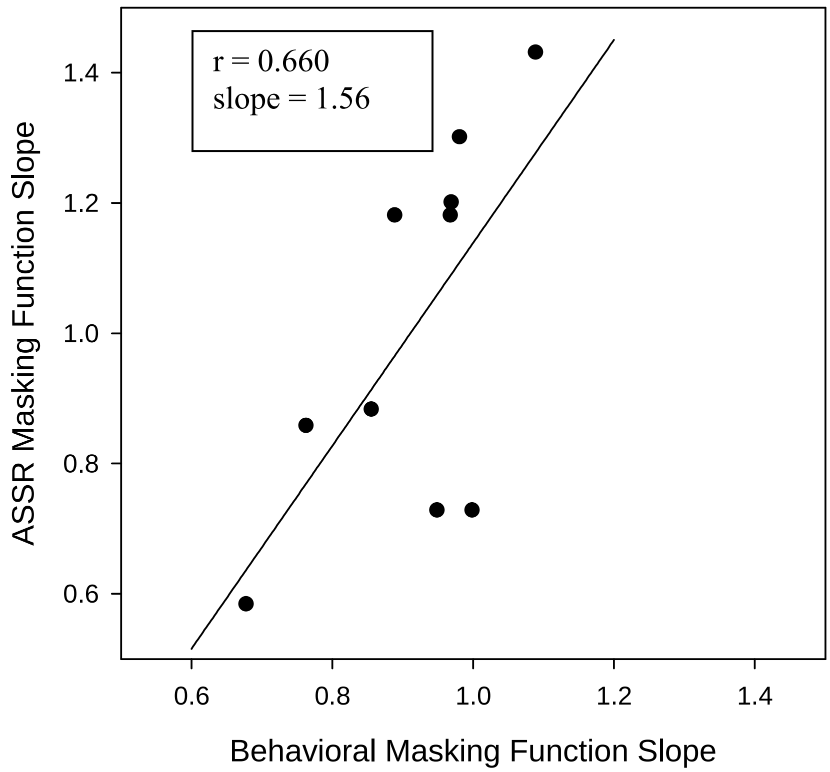

Figure 3.5: Comparison between individual listener behavioral masked threshold slope and *adjusted* ASSR masked threshold slope. The solid line represents the result of linear regression.

3.2 Pooled Data

Data from all 10 listeners was pooled and analyzed in this section. Figure 3.6 plots behavioral threshold shift as a function of BC masking level. In this figure, the abscissa represents the BC masking level, and the ordinate represents the behavioral thresholds. The solid line represents the results of linear regression analysis, which has a slope of 0.845. Behavioral threshold is highly correlated with masking level with a correlation coefficient of 0.900 ($r^2 = 0.810$, $n = 120$, $p < 0.001$, one-tailed).

Figure 3.7 reflects ASSR threshold shift as a function of BC masking level. In this figure, the abscissa represents the BC masking level, and the ordinate represents the ASSR thresholds. The solid line represents the results of linear regression analysis, which has a slope of 0.744. ASSR threshold is highly correlated with masking level with a correlation coefficient of 0.734 ($r^2 = 0.539$, $n = 89$, $p < 0.001$, one-tailed).

Figure 3.8 plots masked thresholds measured behaviorally against masked thresholds recorded by ASSR. The two were strongly correlated with a value of 0.761 ($r^2 = 0.579$, $n = 85$, $p < 0.001$, one-tailed). The solid line, with a slope of 0.798, represents the result of linear regression.

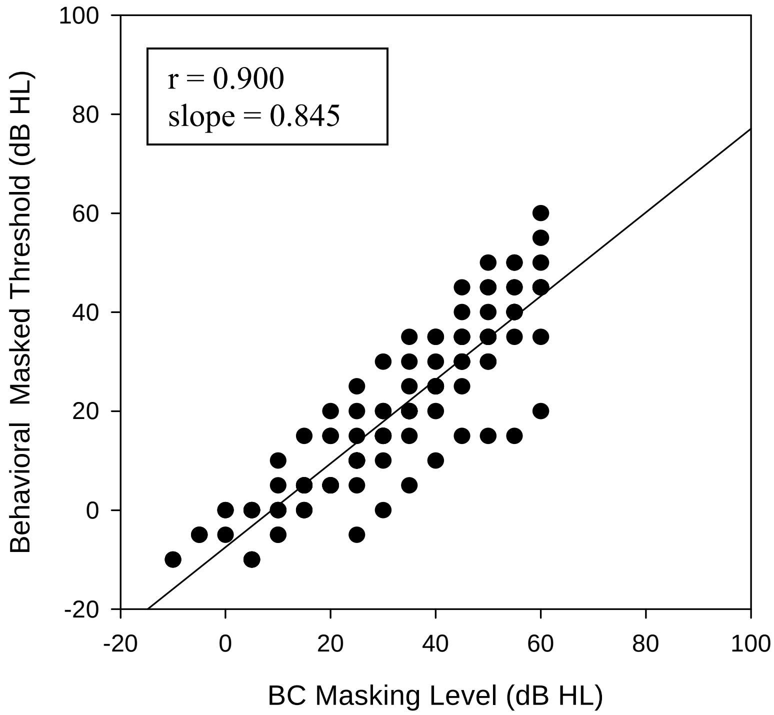

Figure 3.6: Behavioral threshold shift as a function of BC masker level.

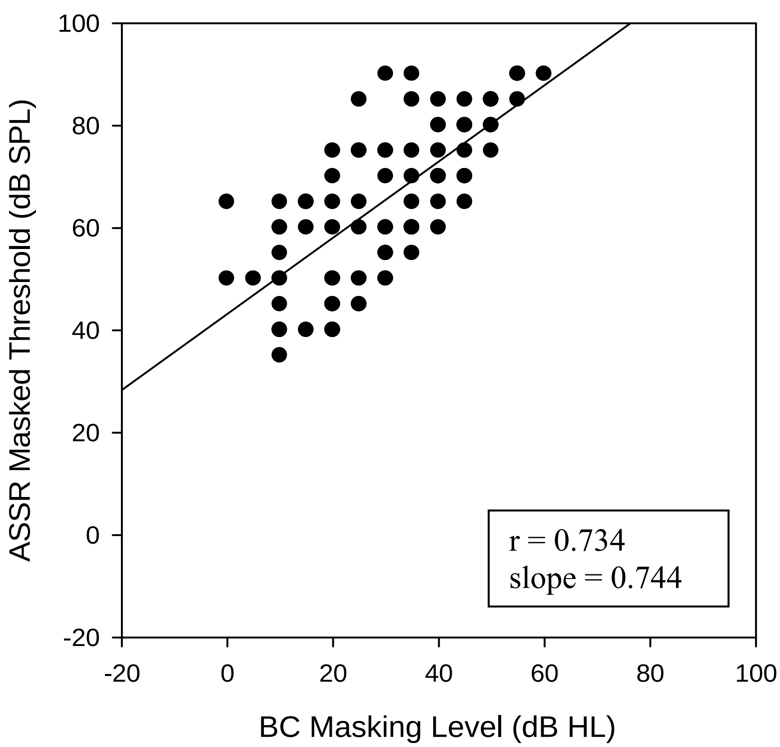

Figure 3.7: ASSR threshold shift as a function of BC masker level.

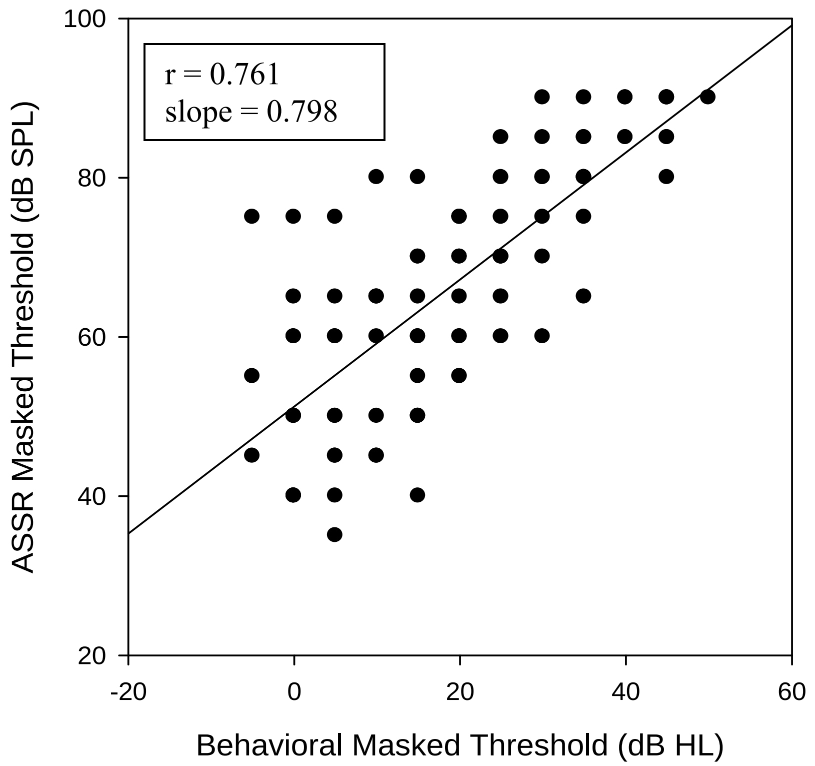

Figure 3.8: ASSR Masked Threshold Plotted Against Behavioral Masked Threshold. The solid line represents the result of linear regression.

CHAPTER 4

DISCUSSION AND CONCLUSIONS

The main goal of this study was to determine whether a bone conducted white noise could effectively and predictably mask ASSR thresholds to a 1 kHz MM stimulus. This was a preliminary measure intended to precede further investigation of the application of the SAL technique to ASSR for air-bone gap estimation.

4.1 Summary and Significance

The high correlation values for pooled behavioral and ASSR masked thresholds measures (Figure 3.6 and 3.7) suggest that the application of bone conducted white noise during the steady-state response recordings of air conducted 1 kHz mixed modulation tones do seem to mask thresholds of normal hearing adult listeners in a generally predictable and consistent manner. The term "generally" is used to refer to the correlation that as masking level increases so do psychoacoustical and ASSR thresholds. Also falling into this "general" level of predictability is the observation that higher masked behavioral thresholds also predict higher ASSR thresholds (Figure 3.8). These pooled data are well fit by linear regression analyses, but it remains that the equations and lines are still being fit to a cloud of data points. In order to attain a better idea of how well masking of ASSR thresholds can be predicted by behavioral measures, a closer look at individual results was required.

The individual comparisons of behavioral and ASSR measures for each listener revealed good agreement. Behavioral and ASSR masked threshold slopes were significantly correlated for both unmodified (Figures 3.4) and modified (Figure 3.5) ASSR data. Comment should be made on the effect of ASSR data modification. As described in the *Results* section, ASSR data was edited to remove the initial "plateau" at the beginning of masked threshold acquisition for several listeners where masking may not have been occurring. If the "plateau" had little or no slope, then it would be expected that unedited ASSR data (which included this plateau) would have a lower overall slope when compared to the edited slope. This was precisely what was observed with a mean unedited data ASSR slope of 0.889 (Table 3.1) and an edited data ASSR slope of 1.01 (Table 3.2). This effect can also be seen in the BTASRs. Since ASSR slope is the divisor for ratio calculation, then an increase in that value would result in a decreased BTASR (1.06 for unedited, 0.961 for edited data).

Another effect of this editing was an increase in the size of standard deviation of the mean BTASRs from 0.196 to 0.237 (Table 3.1 and 3.2, respectively). This could be an effect of reduced sample size, but could have also enhanced the presence of another masking variation in at least two listeners. Listeners 6 and 9 are unusual in the group with adjusted BTASRs of 1.38 and 1.31, respectively (Table 3.2). Their data points are also the obvious outliers in Figure 3.5. Visual observation of their individual masking level functions (Figure 3.1) may reveal a plateau effect at high ASSR masked levels. This raises questions related to whether changes in masking can occur for some individuals at high ASSR and/or high BC masking levels.

Returning to the original research questions asked at the beginning of this study, the results described above do indicate that (1) AC ASSR thresholds can be masked by BC noise, (2) increases in BC noise level result in increases of ASSR threshold levels, and (3) that behavioral masking functions do reasonably predict the occurrence and manner of threshold shift to BC masking noise in ASSR recordings.

4.2 Implications and Future Research

The results of this study provide a necessary step down the road toward application of the SAL technique to ASSR measures as a viable alternative to direct BC measures to estimate the ABG. This work supports the work done by Cone-Wesson and colleagues (2002) by confirming the validity of the underlying assumption of how BC masking of AC ASSR responses occurs. Although their work on differentiating between types of hearing loss in infants is strengthened and the current data give a good indication of predictable and feasible application of a BC masking noise to mask ASSR thresholds, many hurdles remain before this technique is confidently accepted as a clinically useful tool.

One limitation of the current study was the relatively small sample size of 10 listeners. Small samples can lead to larger margins of error and to violations of statistical assumptions (i.e., equal variance, normality). Traditionally, a sample of at least 30 subjects is recommended for tests of statistical significance (although the collection of repeated measures on the same 10 listeners for repeatability and variability analyses may have been a reasonable and, in many ways, more useful alternative). Typically, the result of small sample sizes is that an otherwise significant result (that would occur in a larger sample) could be missed. In light of the potential draw-backs to using a small sample size, significant correlation results were found in this study for all conditions, although one note of comment should be discussed. All correlations presented were calculated using Pearson correlation. This validity of this statistic relies on normality of the data. The comparison between masking level and behavioral threshold (Figure 3.6) was the only case which significant non-normality was observed. As an alternative, the nonparametric Spearman rank (or Spearman's rho) correlation was calculated and gave a similar and slightly higher correlation coefficient of 0.911 ($r^2 = 0.830$, $n = 120$, $p < 0.001$).

During pilot data collection, the fairly short amount of time an individual listener could comfortably be subjected to the 4-5 N of force applied to the head by the bone vibrator headband necessitated the modification described in the methods section (2.2.2). Even with the modification, a two-hour session pushed the limits of comfort for a couple of listeners. Aside from limiting the amount of data that can be collected in such a time, the question was raised to whether an increase in tension associated with discomfort could affect ASSR results. When BC masking levels got close to the limits of the audiometer, an increase in rejections for ASSR recordings also seemed to occur. The residual EEG noise level in an ASSR recording typically varies relatively independently from ASSR response amplitude and is primarily thought to be dependent on muscle activity—being much lower in subjects that are relaxed or sleeping and higher in tense individuals (Picton et al., 2005). While this was not evaluated specifically in this study, the investigation of these variations represents a logical next step in this line of research.

Masked data were collected for this study in a non-random fashion, being of an entirely ascending order. In other words, all masked thresholds were recorded starting at low masking levels and increased in 5 dB steps until the highest level of masking noise was reached. From a research design perspective, randomized data point collection would have been ideal to reduce effects related to order and time (i.e., practice, arousal state, tension, fatigue). A completely randomized masking level design where each individual masking level for every listener would have been collected at random would have substantially (and undesirably) increased ASSR recording duration. Although the increased time requirements would have precluded complete randomization in this study, a reasonable compromise may have been to randomize ascending and descending order of masked threshold collection.

Also quite important is that these data only reflect masking functions generated by normal hearing adults. Certainly the possibility remains that BC masking occurs quite differently for listeners with sensorineural, conductive, or mixed hearing losses. Actually, a limitation of this study is that while an AC pure-tone screening was conducted for all listeners to ensure hearing fell into the normal range, the possibility that a slight ABG could have been present exists. While this likely would not have influenced the results of this study, these data should not be used to make any specific claims about individuals who definitively have no conductive loss. Statements can only be made in the context that they fell into the normal hearing range.

Differences in BC masking between infant/toddler and older adult ages are also a strong possibility. Small and Stapells (2006) describe direct BC ASSR threshold differences between post-term infants and adults. Their results indicated that low-frequency BC thresholds get worse and high-frequency BC thresholds improve with maturation. It is likely that these maturation effects will also need to be investigated and understood for the application of the SAL test to ASSR.

Future research should address the aforementioned areas. In addition, other types of BC noise, AC stimuli, and recording parameters which could produce more robust, predictable, and repeatable responses than those used in this study should be investigated. These are the types of questions that need to be investigated if the application of the SAL test to ASSR is to become a clinically viable tool for estimating ABGs.

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APPENDIX A

INDIVIDUAL AUDIOMETRIC DATA

	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	PTA
Right	10	10	15	0	5	8
Left	10	10	5	10	5	8

Table A.1: Audiometric data for listener 1 (F).

	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	PTA
Right	10	10	10	5	10	8
Left	10	10	10	15	10	12

Table A.2: Audiometric data for listener 2 (F).

	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	PTA
Right	10	10	10	5	5	8
Left	10	10	5	10	5	8

Table A.3: Audiometric data for listener 3 (F).

	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	PTA
Right	15	20	20	15	15	18
Left	15	20	20	15	10	18

Table A.4: Audiometric data for listener 4 (F).

	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	PTA
Right	15	15	10	15	5	13
Left	5	10	10	5	5	8

Table A.5: Audiometric data for listener 5 (F).

	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	PTA
Right	0	0	5	0	0	2
Left	0	0	0	5	0	2

Table A.6: Audiometric data for listener 6 (M).

	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	PTA
Right	5	5	0	0	-10	2
Left	10	10	5	0	5	5

Table A.7: Audiometric data for listener 7 (M).

	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	PTA
Right	15	15	10	15	5	13
Left	10	15	5	15	5	12

Table A.8: Audiometric data for listener 8 (M).

	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	PTA
Right	10	10	10	-5	10	5
Left	10	15	10	5	5	7

Table A.9: Audiometric data for listener 9 (M).

	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	PTA
Right	20	15	20	10	15	15
Left	15	15	20	15	15	17

Table A.10: Audiometric data for listener 10 (M).

APPENDIX B

NBN VS. WTN PILOT DATA

	Masking Level (dB HL)																
	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70
NBN	0	0	0	0	0	5	10	15	15	15	15	15	20	25	30	35	40
WTN	-5	-5	0	0	0	0	5	10	15	20	25	30	30	40	45	NA	NA

Table B.1: Individual behavioral masked thresholds for NBN and WTN for one well-trained listener.

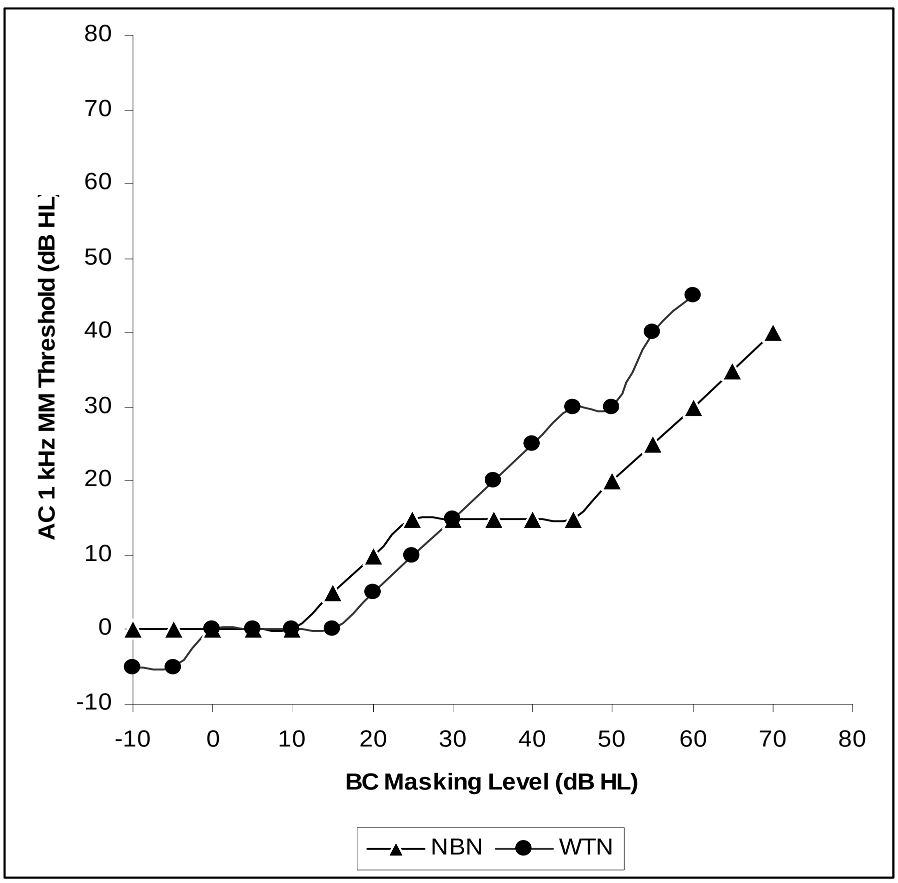

Figure B.1: Scatter plot of behavioral masked thresholds for NBN and WTN.

APPENDIX C

INDIVIDUAL ASSR UNMASKED THRESHOLD DATA

	Unmasked Threshold	
Listener	Behavioral (dB HL)	ASSR (dB SPL)
1	-10*	55
2	-10*	50
3	-10*	45
4	0	50
5	-10*	35
6	-10*	40
7	-10*	40
8	-10*	40
9	-10*	40
10	0	35

Table C.1: Individual unmasked threshold data. *Note: behavioral values of -10 dB represent lowest audiometric setting and do not necessarily represent threshold.

APPENDIX D

INDIVIDUAL MASKED THRESHOLD DATA

BC Level	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60
Behavioral	-10	-5	0	0	10	15	20	25	30	35	35	45	50	50	60
ASSR	NA	NA	65	NA	65	65	75	85	90	90	NA	NA	NA	NA	NA

Table D.1: Individual masked threshold data for listener 1 (F).

BC Level	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60
Behavioral	-10	-10	-5	-5	-5	-5	-5	-5	0	5	10	15	15	15	20
ASSR	NA	NA	NA	NA	60	65	65	75	75	75	80	80	NA	NA	NA

Table D.2: Individual masked threshold data for listener 2 (F).

BC Level	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60
Behavioral	-10	-10	-10	-10	-5	5	5	10	15	20	25	35	40	45	50
ASSR	NA	NA	NA	NA	45	NA	45	NA	50	60	75	80	85	90	NA

Table D.3: Individual masked threshold data for listener 3 (F).

BC Level	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60
Behavioral	0	0	0	0	0	5	5	5	10	15	20	25	30	35	35
ASSR	NA	NA	NA	NA	50	NA	50	60	60	60	70	70	80	NA	NA

Table D.4: Individual masked threshold data for listener 4 (F).

BC Level	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60
Behavioral	-10	-10	-10	-10	0	0	5	10	15	20	25	30	35	40	45
ASSR	NA	NA	NA	NA	40	40	40	45	55	60	70	70	85	90	90

Table D.5: Individual masked threshold data for listener 5 (F).

BC Level	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60
Behavioral	-10	-10	-10	-10	-5	0	5	10	15	20	25	30	35	40	45
ASSR	NA	NA	NA	NA	55	60	60	65	70	70	80	80	80	90	NA

Table D.6: Individual masked threshold data for listener 6 (M).

BC Level	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60
Behavioral	-5	-5	-5	0	0	0	5	10	15	20	25	30	30	40	45
ASSR	NA	NA	NA	NA	50	NA	50	50	60	65	70	75	NA	NA	NA

Table D.7: Individual masked threshold data for listener 7 (M).

BC Level	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60
Behavioral	-5	-5	-5	0	0	5	5	10	15	20	25	35	35	40	45
ASSR	NA	NA	NA	NA	40	NA	45	45	50	55	65	65	75	NA	NA

Table D.8: Individual masked threshold data for listener 8 (M).

BC Level	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60
Behavioral	-10	-5	0	0	0	5	15	20	20	30	35	40	45	50	55
ASSR	NA	NA	50	50	60	65	70	75	75	85	85	85	85	90	NA

Table D.9: Individual masked threshold data for listener 9 (M).

BC Level	-10	-5	0	5	10	15	20	25	30	35	40	45	50	55	60
Behavioral	0	0	0	0	5	5	15	15	20	25	30	35	45	45	45
ASSR	NA	NA	NA	NA	35	NA	40	50	55	60	60	80	80	85	90

Table D.10: Individual masked threshold data for listener 10 (M).